

AD-A048 051

STANFORD UNIV CALIF DIGITAL SYSTEMS LAB
ON THE PLANARITY OF HYPERGRAPHS. (U)

F/G 9/3

UNCLASSIFIED

JUN 77 W M VANCLEEMPOT
DSL-TN-115

N00014-75-C-0601
NL

1 OF 1

AD
A048051



END

DATE
FILMED

1 -78

DDC

AD A 048051

11

FG

ON THE PLANARITY OF HYPERGRAPHS

W. M. vanCleemput

(See back page
for 1473)

Technical Note No. 115

June 1977

DDC
RECEIVED
DEC 28 1977
B

Q

Digital Systems Laboratory
Stanford Electronics Laboratories
Stanford University
Stanford, California 94305

This work was supported by the Joint Services Electronics Program under contract N-00014-75-C-0601.

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

AU NO. —
DDC FILE COPY

Digital Systems Laboratory
Stanford Electronics Laboratories

W. M. vanCleemput

Technical Note No. 115

June 1977

ON THE PLANARITY OF HYPERGRAPHS

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
OK H.P.	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	AVAIL and/or SPECIAL
A	

ABSTRACT

Two definitions for the planarity of a hypergraph will be given. These definitions are related to the problem of modelling circuits for circuit layout. It is shown that if a hypergraph is planar according to the first definition, then it is planar according to the second definition, but the reverse does not hold. Testing the planarity can be done in linear time by using the first definition but requires an enumeration using the second definition. The more accurate model for the circuit layout problem uses the second definition.

INDEX TERMS: Graph theory, hypergraphs, planarity of hypergraphs.

INTRODUCTION

In [4] it is shown that hypergraphs can be used as an abstract model for electronic circuits. When considering the problem of laying out circuits in a single plane the problem of defining the planarity of a hypergraph arises. In [4] the components are modelled by edges of cardinality 2, while the connections are modelled by hyperedges (of cardinality 2 or greater).

In this paper we will derive two definitions for the planarity of a hypergraph and relate these definitions to the circuit layout problem. The first definition allows the testing of planarity in time linearly proportional to the number of vertices and hyperedges. The second definition, however, requires the generation of all possible combinations and does not appear to be polynomially bounded.

It will be shown that, if a hypergraph is planar according to the first definition, then it is planar according to the second definition.

Definition 1:

A hypergraph $H(A, X)$ is an algebraic structure, where A is a set of elements called the vertices and X is a family of non-empty subsets $x(i)$ of A , called hyperedges satisfying $\bigcup_{i=1, |X|} x(i) = A$ (see e.g. [1]).

First Definition of Hypergraph Planarity

Definition 2:

A hypergraph $H(A, X)$ is mapped into a simple graph $G_1(V_1, E_1)$ as follows:

- a) every vertex a of H is mapped into a distinct vertex v' of G_1
 $[v' = f_1(a)]$; let V_1' be the set of all such vertices of G_1 .
- b) every hyperedge x of H is mapped into a star subgraph with a distinct vertex v'' in G_1 , being the center vertex [i.e. $v'' = g_1(x)$] and a collection of edges $\{v'', v\}$ in G_1 , corresponding to each of the vertices v in x . In other words, for every vertex a in a hyperedge x , there is an edge $\{v'', v\}$ in G_1 such that $f_1(a) = v$ and $g_1(x) = v''$; let V_1'' be the set of all center vertices in G_1 corresponding to the hyperedges in H . It is clear that G_1 is a bipartite graph.

Definition 3:

A hypergraph H is planar (first definition) if and only if its associated simple G_1 is planar[†].

This definition of hypergraph planarity can lead to difficulties with respect to the circuit layout problem. Assume that components are modelled by simple subgraphs and nets by proper hyperedges (of which the cardinality can be greater than 2). Then the mapping defined here is not adequate since a net can be realized as any spanning tree on its vertex set.

It can be verified easily that testing the planarity of a hypergraph $H(A, X)$ can be done in time $O(|A| + |X|)$ using Tarjan's algorithm [5] on the associated simple graph.

Second Definition of Hypergraph PlanarityDefinition 4:

A hypergraph $H(A, X)$ is mapped into a collection \mathcal{C} of simple graphs $G_2(V_2, E_2)$ as follows:

- a) Every vertex a of H is mapped into a distinct vertex v' of G_2 [$v' = f_2(a)$]. Let V'_2 be the set of all such vertices of G_2 .
- b) Every hyperedge x of H is mapped into a spanning tree on the set of vertices $\{v(i) \mid v(i) = f_2(a(i)) \text{ and } a(i) \in x\}$.

Definition 5:

A hypergraph is planar (second definition) if and only if there exists an associated simple graph G_2 in the collection \mathcal{C} (as defined above), that is planar.

[†] For a definition of planarity of simple graphs see [3].

Theorem If a hypergraph is planar, according to the first definition, then it is planar according to the second definition.

Proof: Let H be a hypergraph, planar according to the first definition of planarity and let G_1 be its associated simple graph. Then G_1 is planar.

A hyperedge $x = \{a(i), i=1, n\}$ is mapped into a star subgraph of G_1 . Let v be the center vertex and $v(i), i=1, n$ [where $v(i) = f_1(a(i))$], the end vertices of this star subgraph. Apply the following transformation to G_1 : select an edge of the star subgraph and contract it. The resulting graph is still planar. We can repeat this procedure for all hyperedges of H .

The resulting simple graph G_2 satisfies the mapping used to define the planarity according to definition 2. Since G_2 is planar, H is planar according to definition 2.

The converse of this theorem is not true. This can be illustrated by the following example:

The hypergraph in Figure 1 (a) is planar according to the second definition if the hyperedge $\{2,3,5\}$ is mapped into simple edges $\{2,4\}$ and $\{4,5\}$ [Fig. 1 (b)]. But the mapping according to the first definition results in a non-planar graph as shown in Figure 1 (c). Replacing the hyperedge $\{2,4,5\}$ by a star subgraph with a new vertex 6 as the center and with edges $\{6,2\}$, $\{6,4\}$ and $\{6,5\}$ results in one of the well-known Kuratowski graphs i.e. $K_{3,3}$, the complete bipartite graph on six vertices, which is known to be non-planar [3].

The second definition of hypergraph planarity is a better model for the circuit layout problem, since in reality a conductor net can be represented by any connected graph without loops i.e. a tree.

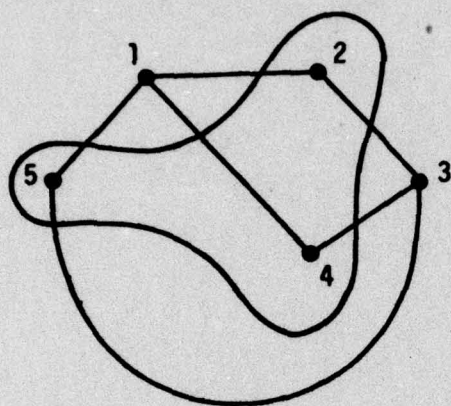
Testing the planarity can no longer be done in linear time since one is required to enumerate all combinations of spanning tree decompositions for each of the hyperedges.

CONCLUSIONS

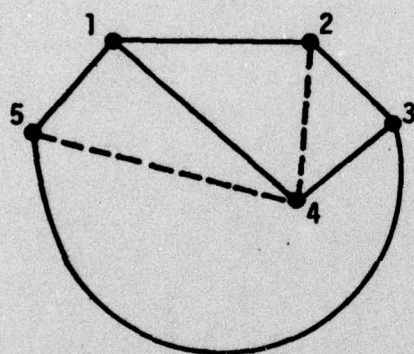
For solving the circuit layout problem optimally, it is necessary to use the second definition of hypergraph planarity. This would require enumerating all spanning trees over all of the hyperedges. Since this is impractical, the less desirable definition of hypergraph planarity is often used in conjunction with the circuit layout problem.

REFERENCES

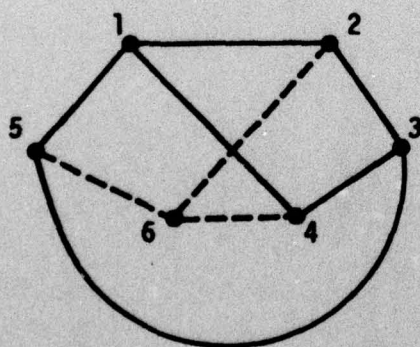
- [1] C. Berge, Graphs and Hypergraphs, Amsterdam: North Holland Publishing Company, 1973.
- [2] W. M. vanCleemput, Mathematical Models and Algorithms for the Circuit Layout Problem, University of Waterloo, Canada, Ph.D. Thesis, 1975.
- [3] F. Harary, Graph Theory, Reading, Mass: Addison Wesley Publishing Company, 1969.
- [4] W. M. vanCleemput, "Hypergraph Models for the Circuit Layout Problem", Applied Mathematical Modelling, vol. 1, pp. 160-161, Dec. 1976.
- [5] J. Hopcroft and R. E. Tarjan, "Efficient Planarity Testing", Journal ACM, vol 21, no. 4, pp. 549-568, Oct. 1974.



(a)



(b)



(c)

Figure 1 Example of a hypergraph (a) that is planar according to the second definition (b) and non-planar according to the first definition (c).

14

DSL-TN-115

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Note No. 115	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ON THE PLANARITY OF HYPERGRAPHS.	5. TYPE OF REPORT & PERIOD COVERED Technical Note	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W. M. vanCleemput	8. CONTRACT OR GRANT NUMBER(s) N00014-75-0601	9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
10. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford Electronics Laboratories Stanford University Stanford, CA 94305	11. REPORT DATE Jun 77	12. NO. OF PAGES 9 p.
13. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Department of the Navy Washington, DC 22217	14. SECURITY CLASS. (of this report)	15. DECLASSIFICATION/DOWNGRADING SCHEDULE
14. MONITORING AGENCY NAME & ADDRESS (if diff. from Controlling Office)	16. DISTRIBUTION STATEMENT (of this report) Reproduction in whole or part is permitted for any purpose of the United States Government	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from report) Approved for public release Distribution Unlimited		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Graph theory, hypergraphs, planarity of hypergraphs		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Two definitions for the planarity of a hypergraph will be given. These definitions are related to the problem of modelling circuits for circuit layout. It is shown that if a hypergraph is planar according to the first definition, then it is planar according to the second definition, but the reverse does not hold. Testing the planarity can be done in linear time by using the first definition but requires an enumeration using the second definition. The more accurate model for the circuit layout problem uses the second definition.		

DD FORM 1473

EDITION OF 1 NOV 66 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

JSEP REPORTS DISTRIBUTION LIST

	<u>No. of Copies</u>		<u>No. of Copies</u>
<u>Department of Defense</u>		Dr. R. Reynolds	1
Defense Documentation Center		Defense Advanced Research	
Attn: DDC-TCA (Mrs. V.Caponio)	12	Projects Agency	
Cameron Station		Attn: Technical Library	
Alexandria, Virginia 22314		1400 Wilson Boulevard	
		Arlington, Virginia 22209	
Asst. Dir., Electronics	1		
and Computer Sciences		<u>Department of the Air Force</u>	
Office of Director of Defense		AF/RDPS	1
Research and Engineering		The Pentagon	
The Pentagon		Washington, D.C. 20330	
Washington, D.C. 20315			
Office of Director of Defense	1	AFSC (LJ/ Mr. Irving R. Mirman)	1
Research and Engineering		Andrews Air Force Base	
Information Office Lib. Branch		Washington, D.C. 20334	
The Pentagon			
Washington, D.C. 20301		Directorate of Electronics	1
		and Weapons	
ODDR&E Advisory Group on	1	HQ AFSC/DLC	
Electron Devices		Andrews AFB, Maryland 20334	
201 Varick Street			
New York, New York 10014		Directorate of Science	1
		HQ AFSC/DLS	
Chief, R&D Division (340)	1	Andrews Air Force Base	
Defense Communications Agency		Washington, D.C. 20334	
Washington, D.C. 20301			
Director, Nat. Security Agency	1	LTC J.W. Gregory	5
Fort George G. Meade		AF Member, TAC	
Maryland 20755		Air Force Office of	
Attn: Dr. T.J.Beahn		Scientific Research	
		Bolling Air Force Base	
Institute for Defense Analysis	1	Washington, D.C. 20332	
Science and Technology Division			
400 Army-Navy Drive		Mr. Carl Sletten	1
Arlington, Virginia 22202		RADC/ETE	
		Hanscom AFB, Maryland 01731	
Dr. Stickley	1	Dr. Richard Picard	1
Defense Advanced Research		RADC/ETSL	
Projects Agency		Hanscom AFB, Maryland 01731	
Attn: Technical Library			
1400 Wilson Boulevard		Mr. Robert Barrett	1
Arlington, Virginia 22209		RADC/ETS	
		Hanscom AFB, Maryland 01731	

	<u>No. of Copies</u>		<u>No. of Copies</u>
Dr. John N. Howard AFGL/CA Hanscom AFB, Maryland 01731	1	Mr. John Mott-Smith HQ ESD (AFSC) MCIT - Stop 36 Hanscom AFB, MA. 01731	1
Dr. Richard B. Mack RADC/ETER Hanscom AFB, Maryland 01731	1	LTC Richard J. Gowen Professor Dept. of Electrical Engineering USAF Academy, Colorado 80840	1
Documents Library (TILD) Rome Air Development Center Griffiss AFB, New York 13441	1	AUL/LSE-9663 Maxwell AFB, Alabama 36112	1
Mr. H.E. Webb, Jr. (ISCP) Rome Air Development center Griffiss AFB, New York 13441	1	AFETR Technical Library P.O. Box 4608, MU 5650 Patrick AFB, Florida 32542	1
Mr. Murray Kesselman (ISCA) Rome Air Development Center Griffiss AFB, New York 13441	1	ADTC (DLOSL) Eglin AFB, Florida 32542	1
Mr. W. Edwards AFAL/TE Wright-Patterson AFB Ohio 45433	1	HQ AMD (RDR/Col. Godden) Brooks AFB, Texas 78235	1
Mr. R.D. Larson AFAL/DHR Wright-Patterson AFB Ohio 45433	1	USAF European Office of Aerospace Research Technical Information Office Box 14, FPO, New York 09510	1
Howard H. Steenbergen AFAL/DHE Wright-Patterson AFB Ohio 45433	1	Dr. Carl E. Baum AFWL (ES) Kirtland AFB, New Mexico 87117	1
Chief Scientist AFAL/CA Wright-Patterson AFB Ohio 45433	1	ASAFSAM/RAL Brooks AFB, Texas	1
HQ ESD (DRI/Stop22) Hanscom AFB, Maryland 01731	1	<u>Department of the Army</u> HQDA (DAMAOARZ-A) Washington, D.C. 20310	1
Professor R.E. Fontana Head, Dept. of Electrical Engr. AFIT/ENE Wright-Patterson AFB Ohio 45433	1	Commander U.S. Army Security Agency Attn: IARD-T Arlington Hall Station Arlington, Virginia 22212	1

	<u>No. of Copies</u>		<u>No. of Copies</u>
Commander U.S. Army Materiel Dev. & Readiness Command Attn: Tech. Library Rm 7S 35 5001 Eisenhower Ave. Alexandria, Virginia 22333	1	Commander Harry Diamond Laboratories ATTN: Mr. John E. Rosenberg 2800 Posder Mill Road Adelphi, Maryland 20783	1
Commander Research Laboratory ATTN. DRXRD-BAD U.S. Army Ballistics Aberdeen Proving Ground Aberdeen, Maryland 21005	1	Commandant U.S. Army Air Defense School Attn: ATSAD-T-CSM Fort Bliss, Texas 79916	1
Commander Picatinny Arsenal Dover, New Jersey 07081 ATTN: SMUPA-TS-T-S	1	Commandant U.S. Army Command and General Staff College Attn: Acquisition, Library Div Fort Leavenworth, Kansas 66027	1
ATTN: Dr. Herman Robl U.S. Army Research Office P.O. Box 12211 Research Triangle Park North Carolina 27709	1	Dr. Hans K. Ziegler (AMSEL-TL-D) Army Member, TAC/JSEP U.S. Army Electronics Command (DRSEL-TL-D) Fort Monmouth, New Jersey 07703	1
ATTN: MR. Richard O. Ulsh U.S. Army Research Office P.O. Box 12211 Research Triangle Park North Carolina 27709	1	Mr. J.E. Teti (AMSEL-TL-DT) Executive Secretary, TAC/JSEP U.S. Army Electronics Command (DRSEL-TL-DT) Fort Monmouth, New Jersey 07703	3
Mr. George C. White, Jr. Deputy Director Pitman-Dunn Laboratory Frankford Arsenal Philadelphia, Penna. 19137	1	Director Night Vision Laboratory, ECOM ATTN: DRSEL-NV-D Fort Belvoir, Virginia 22060	1
Commander Attn: Chief, Document Section U.S. Army Missile Command Redstone Arsenal, Alabama 35809	1	Commander/Director Atmospheric Sciences Laboratory (ECOM) Attn: DRSEL-BL/DD White Sands Missile Range New Mexico 88002	1
Commander U.S. Army Missile Command Attn: DRSMI-RR Redstone Arsenal, Alabama 35809	1	Director Electronic Warfare Lab., ECOM Attn: DRSEL-WL-MY White Sands Missile Range New Mexico 88002	1
Commander Chief, Materials Sciences Division, Bldg. 292 Army Materials and Mechanics Research Center Watertown, Massachusetts 02172		Commander US Army Armament Command Attn: DRSAR-RD Rock Island, Illinois 61201	1

	<u>No. of Copies</u>		<u>No. of Copies</u>
Project Manager	1	NL-H Dr. F. Schwering	1
Ballistic Missile Defense Program		TL-E Dr. S. Kronenberg	1
Office		TL-E Dr. J. Kohn	1
Attn: DACS-BMP (Mr. A. Gold)		TL-I Dr. C. Thornton	1
1300 Wilson Blvd.		NL-B Dr. S. Amorsos	1
Washington, D.C. 22209			
Director, Division of Neuropsychiatry		Col. Robt. W. Noce	
Walter Reed Army Institute	1	Senior Standardization Rep.	1
of Research		U.S. Army Standardization	
Washington, D.C. 20012		Group, Canada	
		Canadian Force Headquarters	
		Ottawa, Ontario, Canada KIA OK2	
Commander, USASATCOM	1		
Fort Monmouth, New Jersey 07703		Commander	
		CCOPS-PD	
Commander, U.S. Army	1	Fort Huachuca, Arizona 85613	
Communications Command		Attn: H.A. Lasitter	
Attn: Director, Advanced Concepts			
Office		<u>Department of the Navy</u>	
Fort Huachuca, Arizona 85613		Dr. Sam Koslov	1
Project Manager, ARTADS	1	ASN (R&D)	
EAI Building		Room 4E741	
West Long Branch, N.J. 07764		The Pentagon	
		Washington, D.C. 20350	
U.S. Army White Sands Missile Range			
STEWS-ID-R	1	Office of Naval Research	1
Attn: Commander		800 N. Quincy Street	
White Sands Missile Range		Arlington, Virginia 22217	
New Mexico 88002		Attn: Codes 100	
		102	
Mr. William T. Kawai		201	
U.S. Army R&D Group (Far East)	1	220	
APO, San Francisco, Ca. 96343		221	
		401	
Director, TRI-TAC	1	420	
Attn: TT-AD (Mrs. Briller)		421	
Fort Monmouth, N.J. 07703		427 (All Hands)	
		432	
Commander		437	
U.S. Army Electronics Command	1		
Fort Monmouth, N.J. 07703		Naval Research Laboratory	
Attn: AMSEL-RD-O (Dr. W.S. McAfee)	1	4555 Overlook Aven. SW	
CT-L (Dr. G. Buser)	1	Washington, D.C. 20375	
NL-O (Dr. H.S. Bennett)	1	Attn: Codes 4000 - Dr. A Berman	
NL-T (Mr. R. Kulinyi)	1	4105 - Dr. S. Teitler	
TL-B	1	4207 - Dr. J. McCaffrey	
VL-D	1	5000 - Dr. H. North	
WL-D	1	5200 - Mr. A. Brodzinsky	
TL-MM (Mr. Lipetz)	1	5203 - Dr. L. Young	
(cont'd)		5210 - Dr. J. Davey	

	<u>No. of Copies</u>		<u>No. of Copies</u>
Naval Surface Weapons Center White Oak Silver Spring, Maryland 20910 Attn: Codes WR - 04 - W. Scanlon WR - 30 - Dr. J. Dixon WR - 303 - Dr. R. Allgaier WR - 34 - H.R. Riedl WR - 43 - P. Wessel	1	Dr. W. A. VonWinkle Associate Technical Director for Technology Naval Underwater Systems Center New London, Connecticut 06320 Officer in Charge Naval Underwater Systems Center Newport, Rhode Island 02840	1 1
Naval Surface Weapons Center Dahlgren, Virginia 22448 Attn: Codes DF - J. Mills DF - 14 - K. Ferris DF - 36 - S. Leong	1	Dr. H.L. Blood Technical Director Naval Undersea Center San Diego, Calif. 95152	1
Naval Air Development Center Johnsville Warminster, Penna 18974 Attn: Codes 01 - Dr. R. Lobb 202 - T. Shopple 20212 - S. Campagna 2022 - G. Fer	1	Dr. Robert R. Fossum Dean of Research Naval Postgraduate School Monterey, Calif. 93940	1
Dr. Gernot M.R. Winkler Director, Time Service U.S. Naval Observatory Mass. Ave. at 34th St., N.W. Washington, D.C. 20390	1	Naval Electronics Laboratory Center 271 Catalina Blvd. San Diego, Calif. 92152 Attn: Codes 0220 - H.T. Mortimer 2000 - P.C. Fletcher 2020 - V.E. Hildebrand 2100 - C.A. Nelson 2200 - J. Ritcher 2300 - C.W. Erickson 2400 - F.M. Tripak 2500 - W.E. Richards 3000 3400 - R. Coburn 4000 - C.E. Pierson 4600 - I. Lagnado 5000 - A.E. Beutel 5200 - R.R. Eyres 5300 - P.H. Johnson 5600 - W.J. Dejka	1
Officer in Charge Carderock Laboratory David Taylor Naval Ship Research and Development Center Bethesda, Maryland 20034	1		
Officer in Charge Annapolis Laboratory Naval Ship Research & Development Center Annapolis, Maryland 21402	1		
Dr. G. Gould, Technical Director Naval Coastal Systems Laboratory Panama City, Florida 32401	1	Naval Weapons Center China Lake, Calif. 93555 Attn: Codes 60 - Royce 601 - F.C. Essig 6013 - V.L. Rehn 6014 - D.J. White 6018 - J.M. Bennett 6019 - N. Bottka (cont'd)	1
M.J. Wynn Code 790 Naval Coastal Systems Laboratory Panama City, Florida 32401	1		

	<u>No of Copies</u>		<u>No. of Copies</u>
Naval Weapons Center		Robert E. Frischell	1
China Lake, Calif. 93555		Johns Hopkins University	
Attn: Codes 605 - W.S. McEwan	1	Applied Physics Laboratory	
5515 - M.H. Ritchie		Laurel, Maryland 20810	
3945 - D.G. McCauley			
5525 - Webster		Mr. G.H. Gleissmer	1
35 - D.J. Russell		Code 18	
55 - B.W. Hayes		David Taylor Naval Ship R&D Center	
3544 - H.W. Swinford		Bethesda, Maryland 20084	
3815 - R.S. Hughes			
D.E. Kirk	1	Commander	1
Professor & Chairman, Electronic		Pacific Missile Test Center	
Engineering		Code 4253-3	
Sp-304		Point Mugu, Calif. 93042	
Naval Postgraduate School			
Monterey, Calif. 93940		Richard Holden	1
		DF - 34	
Professor Sydney P. Parker	1	Naval Surface Weapons Center	
Electrical Engineering Sp-62		Dahlgren Laboratory	
Naval Postgraduate School		Dahlgren, Virginia 22448	
Monterey, Calif. 93940			
		<u>Other Government Agencies</u>	
Dr. Roy F. Potter	1	Mr. F.C. Schwenk, RD-T	1
3868 Talbot Street		National Aeronautics and	
San Diego, Calif. 92106		Space Administration	
		Washington, D.C. 20546	
Mr. J.C. French	1		
Electronics Technology Division		Los Alamos Scientific Lab	1
National Bureau of Standards		Attn: Reports Library	
Washington, D.C. 20234		P.O. Box 1663	
		Los Alamos, New Mexico 87544	
John L. Allen	1		
Deputy Director (Research & Advanced		M. Zane Thornton	1
Technology)		Deputy Director,	
ODDR&E		Institute for Computer	
The Pentagon, Room 3E114		Sciences & Technology	
Washington, D.C. 20301		National Bureau of Standards	
		Washington, D.C. 20550	
Leonard R. Weisberg	1		
Assistant Director (Electronics		Director, Office of Postal	1
& Physical Sciences)		Technology (R&D)	
ODDR&E		U.S. Postal Service	
The Pentagon		11711 Parklawn Drive	
Washington, D.C. 20301		Rockville, Maryland 20852	
George Gamota	1		
Staff Specialist for Research		NASA Lewis Research Center	1
ODDR&E		Attn: Library	
The Pentagon, Room 3D1079		21000 Brookpark Road	
Washington, D.C. 20301		Cleveland, Ohio 44135	

	<u>No. of Copies</u>		<u>No. of Copies</u>
Library - R51	1	Director	1
Bureau of Standards		Columbia Radiation Laboratory	
Acquisition		Department of Physics	
Boulder, Colorado 80302		Columbia University	
		538 West 120th Street	
MIT Lincoln Laboratory	1	New York, New York 10027	
Attn: Library A-082			
P.O. Box 73		Director	1
Lexington, Mass. 02173		Electronics Research Laboratory	
		University of California	
Dr. Jay Harris	1	Berkeley, Calif. 94720	
Program Director, Devices and			
Waves Program		Director	1
National Science Foundation		Electronics Sciences Laboratory	
1800 G. Street		University of Southern California	
Washington, D.C. 20550		Los Angeles, California 90007	
Dr. Howard W. Etzel, Deputy Director		Director	1
Division of Materials Research	1	Electronics Research Center	
National Science Foundation		The University of Texas at Austin	
1800 G. Street		Engineering-Science Bldg. 112	
Washington, D.C. 20550		Austin, Texas 78712	
Dr. Dean Mitchell, Program Director		Director of Laboratories	1
Solid-State Physics	1	Division of Engineering and	
Div. of Materials Research		Applied Physics - Tech. Reports	
National Science		Collection	
		Harvard University	
<u>Non-Government Agencies</u>		Pierce Hall	
Director	1	Cambridge, Massachusetts 02138	
Research Lab. of Electronics			
Massachusetts Inst. of Tech.			
Cambridge, Mass. 02139			
Director	1		
Microwave Research Institute			
Polytechnic Inst. of New York			
Long Island Graduate Center			
Route 110			
Farmingdale, New York 11735			
Assistant Director			
Microwave Research Institute			
Polytechnic Inst. of New York			
333 Jay Street			
Brooklyn, New York 11201			